CLAIMS

1. An optical transmission system comprising:

an optical transmitter which outputs differential-encoded phase-modulated light; and

an optical receiver which detects the phase-modulated light and performs demodulation,

wherein the optical transmitter comprises: an encoder which converts NRZ code input signals into NRZ-I code signals; and a phase modulator which, for marks and spaces encoded by the encoder, outputs phase-modulated light with a phase deviation $\Delta\phi$ imparted over a range $0 \leq \Delta\phi \leq \pi$,

the optical receiver comprises:

a Mach-Zehnder interferometer with phase-adjustment terminal to set a phase difference between two interfering signals, which splits the phase-modulated light which has been received into two signal light beams, delays one of the split signal light beams by one bit, and causes the two signal light beams to interfere to effect conversion into intensity-modulated light;

a balanced detection circuit which performs photoelectric conversion of signal light from two output ports of the Mach-Zehnder interferometer, and outputs a difference in converted electrical signals;

a low-frequency signal generation circuit which applies a first low-frequency signal at frequency f1 to the phase-adjustment terminal of the Mach-Zehnder interferometer;

an infinitesimal-modulated signal component detection circuit which detects a second low-frequency signal from a signal supplied by the balanced detection circuit;

a synchronous detection circuit which, by synchronous detection of the second low-frequency signal output from the infinitesimal-modulated signal component detection circuit using the first low-frequency signal output from the low-frequency signal generation circuit, detects a shift amount and direction of shift between a center wavelength of the phase-modulated light output from the optical transmitter and a pass band wavelength of the Mach-Zehnder interferometer;

a control circuit which outputs a control signal to adjust the phase difference between the two split signal light beams so as to correct the shift amount; and

a driver circuit which drives the phase adjustment terminal based on the control signal.

2. The optical transmission system according to Claim 1,

wherein the infinitesimal-modulated signal component detection circuit comprises: an eye-opening monitoring circuit which outputs a signal obtained by monitoring an eye opening of a signal split from the signal output from the balanced detection circuit; and a band-pass filter which passes the second low-frequency signal contained in the signal output from the eye-opening monitoring circuit,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

3. The optical transmission system according to Claim 1,

wherein the infinitesimal-modulated signal component detection circuit comprises: a data regeneration circuit which discriminates and regenerates an electrical signal output from the balanced detection circuit and which is provided with a code error detection function; an error count monitoring circuit which outputs a signal obtained by monitoring the number of errors output from the data regeneration circuit; and a band-pass filter which passes the second low-frequency signal contained in the signal output from the error count monitoring circuit,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

4. The optical transmission system according to Claim 1,

wherein the balanced detection circuit comprises an equalizing amplification circuit,

the infinitesimal-modulated signal component detection circuit comprises: a current consumption monitoring circuit which outputs a signal obtained by monitoring the current consumption of the equalizing amplification circuit; and a band-pass filter which passes the second low-frequency signal contained in the signal output by the current consumption monitoring circuit,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

5. The optical transmission system according to Claim 1,

wherein the balanced detection circuit comprises: an optical splitting unit which splits into two each of the two output ports of the Mach-Zehnder interferometer; an

optical coupling unit which causes interference between two light beams split by the optical splitting unit; and an optical detection unit which converts an optical signal output from the optical coupling unit into an electrical signal,

the infinitesimal-modulated signal component detection circuit comprises a band-pass filter which passes the second low-frequency signal contained in the electrical signal output from the optical detection unit,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

6. The optical transmission system according to Claim 1,

wherein a free spectral range of the Mach-Zehnder interferometer is shifted somewhat from the clock rate of a main signal,

the infinitesimal-modulated signal component detection circuit comprises: a first amplifier which amplifies an optical current of one of photodetectors forming the balanced optical detection circuit; and a band-pass filter which extracts a component of the second low-frequency signal from an output of the first amplifier,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

7. The optical transmission system according to Claim 6,

wherein the infinitesimal-modulated signal component detection circuit further comprises: a second amplifier which amplifies an optical current of the other of the photodetectors forming the balanced detection circuit; and a subtracter which outputs a difference between an output of the first amplifier and an output of the second amplifier,

the band-pass filter extracts the component of the second low-frequency signal from an output of the subtracter.

8. The optical transmission system according to Claim 1,

wherein the infinitesimal-modulated signal component detection circuit comprises: a clock extraction circuit which extracts a clock signal from a signal train output from the balanced detection circuit; and a low-frequency signal extraction circuit which extracts the second low-

frequency signal superposed on the clock signal output from the clock extraction circuit,

the synchronous detection circuit detects the shift amount and direction based on the second low-frequency signal output from the low-frequency signal extraction circuit.

9. The optical transmission system according to Claim 1,

wherein the optical transmitter comprises: a clock signal generation circuit which generates a clock signal having the same bit rate as a signal bit rate; and an intensity modulator which performs intensity modulation of the phase-modulated light using the clock signal output by the clock signal generation circuit,

the balanced detection circuit comprises: an optical splitting circuit which splits one of the two output ports of the Mach-Zehnder interferometer; and a monitoring photodetector connected to the optical splitting circuit,

the infinitesimal-modulated signal component detection circuit comprises: a narrow-band amplifier which extracts a clock on which the second low-frequency signal is superposed from intensity-modulated light output from the monitoring photodetector; and a power detection circuit

which extracts the second low-frequency signal from the extracted clock,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the power detection circuit.

10. The optical transmission system according to Claim 1, wherein the infinitesimal-modulated signal component detection circuit comprises: a data regeneration circuit which discriminates and regenerates an electrical signal output from the balanced detection circuit; a correlation detection circuit which detects a correlation between an output signal of the data regeneration circuit and a signal before discrimination; and a low-frequency signal extraction circuit which extracts the second low-frequency signal from an output of the correlation detection circuit.

11. The optical transmission system according to Claim 1,

wherein the optical transmission system comprises: an intensity modulation unit which performs intensity modulation of the phase-modulated light using a signal at frequency f2 sufficiently high to enable superpositioning of the low-frequency signal at frequency f1; and an

intensity-modulated component detection unit which detects an intensity-modulated component at frequency f2,

the infinitesimal-modulated signal component detection circuit extracts the second low-frequency signal at frequency f1 superposed onto the detected intensity-modulated component at frequency f2.

12. The optical transmission system according to Claim 11, wherein, as the intensity modulation unit, the optical transmitter comprises an oscillation circuit which generates a signal at the frequency f2 and performs direct intensity modulation of a light source of the optical transmitter.

13. The optical transmission system according to Claim 11, wherein, as the intensity modulation unit, the optical receiver comprises: an oscillation circuit which generates a signal at the frequency f2; and an intensity modulator which performs intensity modulation of signal light using the signal output from the oscillation circuit.

14. The optical transmission system according to Claim 11, wherein, as the intensity modulation unit, the optical receiver comprises: an oscillation circuit which generates a signal at the frequency f2; and an optical

amplifier connected to the oscillation circuit, and that the gain of the optical amplifier is modulated by the oscillation circuit at the frequency f2.

15. The optical transmission system according to any one of Claims 11 through 14, wherein, as the intensity-modulated component detection unit, the optical receiver comprises: an optical splitting circuit which splits one of the two output ports of the Mach-Zehnder interferometer; a monitoring photodetector connected to the optical splitting circuit; and an extraction circuit which extracts the component at the frequency f2 from intensity-modulated light output from the monitoring photodetector.

16. The optical transmission system according to any one of Claims 11 through 14, wherein, as the intensity-modulated component detection unit, the optical receiver comprises: an input level adjustment unit which renders asymmetric the input levels of the converted intensity-modulated light which is input to the balanced detection circuit; and an extraction circuit which extracts the component at the frequency f2 from an output signal of the balanced detection circuit.

17. The optical transmission system according to any one of Claims 1 to 16,

wherein the infinitesimal-modulated signal component detection circuit comprises a data regeneration circuit which discriminates and regenerates an electrical signal output from the balanced detection circuit,

the optical receiver further comprises: a logic inversion circuit which inverts the logic of an output signal of the data regeneration circuit and outputs an inverted signal; a selection unit which selectively outputs either the output signal of the data regeneration circuit or an output of the logic inversion circuit according to a prescribed logic specification signal; and a polarity selection unit which inverts the polarity of a feedback error signal within the control circuit when the output of the logic inversion circuit has been selected,

an amount of correction of the shift between the center wavelength of the phase-modulated light output from the optical transmitter and the pass band wavelength of the Mach-Zehnder interferometer is reduced to 1/2 or less of a repetition frequency of the Mach-Zehnder interferometer.

18. The optical transmission system according to any one of Claims 1 through 17,

wherein the optical receiver further comprises: a temperature detection circuit which detects the temperature of a substrate of the Mach-Zehnder interferometer; and a loop open/close switch which turns on and off feedback control to the Mach-Zehnder interferometer,

when the temperature of the substrate of the Mach-Zehnder interferometer is not within an appropriate range, the loop to perform the feedback control is opened, whereas when the temperature of the substrate of the Mach-Zehnder interferometer is within the appropriate range, the loop is closed to perform the feedback control.

19. The optical transmission system according to any one of Claims 1 through 17,

wherein the control circuit further comprises: a lock detection circuit which detects a locked state of a loop which performs feedback control to the Mach-Zehnder interferometer; and a re-locking circuit which re-locks the loop when the locked state indicates that the loop is unlocked,

when the lock detection circuit is detecting that the loop is locked, normal feedback control is performed, and when the lock detection circuit is not detecting that the loop is locked, a driving signal applied to the phase adjustment terminal of the Mach-Zehnder interferometer is

swept, and if the lock detection circuit once again detects that the loop is locked, switching to a state in which the normal feedback control is performed.

20. The optical transmission system according to any one of Claims 1 through 17, wherein the Mach-Zehnder interferometer is provided with two independent phase adjustment terminals, and an output of the infinitesimal-modulated signal oscillation circuit is applied to one of the two phase adjustment terminals, while a feedback error signal within the control circuit is applied to the other of the two phase adjustment terminals.

21. The optical transmission system according to any one of Claims 1 through 17,

wherein the optical receiver comprises: an optical carrier frequency detection unit which detects, from received signal light detected by the balanced detection circuit, a relative position between an optical carrier frequency and an optical frequency characteristic of the Mach-Zehnder interferometer; and an offset setting circuit which provides an offset to a feedback error signal in the control circuit,

a value of the offset of the offset setting circuit is adjusted such that the position of the optical carrier

frequency matches a peak position or bottom position of the optical frequency characteristic of the Mach-Zehnder interferometer.

22. The optical transmission system according to any one of Claims 1 through 17,

wherein the optical transmitter comprises: a modulation state control unit which turns on and off modulation of a main signal; and a first control signal communication unit which communicates with the optical receiver using a control line provided separately from a line for the main signal,

the optical receiver comprises: an optical carrier frequency detection unit which detects, from received signal light detected by the balanced detection circuit, a relative position between an optical carrier frequency and an optical frequency characteristic of the Mach-Zehnder interferometer; an offset setting circuit which provides an offset to a feedback error signal in the control circuit; and a second control signal communication unit which communicates with the optical transmitter using the control line,

at the time of startup of the optical transmission system, the optical transmitter uses the modulation state control unit to turn off modulation of the main signal and

transmit only an optical carrier, the optical receiver uses the optical carrier frequency detection unit to detect the relative position between the frequency of the optical carrier transmitted from the optical transmitter and the optical frequency characteristic of the Mach-Zehnder interferometer, and adjusts the offset of the offset setting circuit so as to cause a position of the optical carrier frequency to match a peak or bottom position of the optical frequency characteristic of the Mach-Zehnder interferometer, the optical receiver sends a control signal indicating completion of offset adjustment to the optical transmitter using the second control signal communication unit, and, after receiving the control signal, the optical transmitter turns on modulation of the main signal.

23. An optical transmitter, in an optical transmission system comprising: the optical transmitter which outputs differential-encoded, phase-modulated light; and an optical receiver which detects the phase-modulated light and performs demodulation, wherein the optical transmitter comprises: an encoder which converts NRZ code input signals into NRZ-I code signals; and a phase modulator which, for marks and spaces encoded by the encoder, outputs phase-modulated light with a phase deviation $\Delta\phi$ imparted over a range $0 \leq \Delta\phi \leq \pi$, the optical receiver comprises: a Mach-Zehnder interferometer with

phase-adjustment terminal to set a phase difference between two interfering signals, which splits the phase-modulated light which has been received into two signal light beams, delays one of the split signal light beams by one bit, and causes the two signal light beams to interfere to effect conversion into intensity-modulated light; and a balanced photodetector which performs photoelectric conversion of signal light from two output ports of the Mach-Zehnder interferometer, and outputs a difference in converted electrical signals,

the optical transmitter comprises: a clock signal generation circuit which generates a clock signal having the same bit rate as a signal bit rate; and an intensity modulator which uses the clock signal output from the clock signal generation circuit to perform intensity modulation of the phase-modulated light.

24. An optical transmitter, in an optical transmission system comprising: an optical transmitter which outputs differential-encoded, phase-modulated light; and an optical receiver which detects the phase-modulated light and performs demodulation, wherein the optical transmitter comprises: an encoder which converts NRZ code input signals into NRZ-I code signals; and a phase modulator which, for marks and spaces encoded by the encoder, outputs phase-modulated light with a phase

deviation $\Delta\phi$ imparted over a range $0 \leq \Delta\phi \leq \pi$, the optical receiver comprises: a Mach-Zehnder interferometer with phase-adjustment terminal to set a phase difference between two interfering signals, which splits the phase-modulated light which has been received into two signal light beams, delays one of the split signal light beams by one bit, and causes the two signal light beams to interfere to effect conversion into intensity-modulated light; and a balanced photodetector which performs photoelectric conversion of signal light from two output ports of the Mach-Zehnder interferometer, and outputs a difference in converted electrical signals,

the optical transmitter comprises an oscillation circuit which generates a signal at frequency f2 sufficiently high to enable superpositioning of a low-frequency signal at frequency f1 at which a light source of the optical transmitter is directly intensity-modulated.

25. An optical receiver, in an optical transmission system comprising: an optical transmitter which outputs differential-encoded, phase-modulated light; and the optical receiver which detects the phase-modulated light and performs demodulation, wherein the optical transmitter comprises: an encoder which converts NRZ code input signals into NRZ-I code signals; and a phase modulator which, for

marks and spaces encoded by the encoder, outputs phase-modulated light with a phase deviation $\Delta\phi$ imparted over the range $0 \leq \Delta\phi \leq \pi$,

the optical receiver comprises:

a Mach-Zehnder interferometer with phase-adjustment terminal to set a phase difference between two interfering signals, which splits the phase-modulated light which has been received into two signal light beams, delays one of the split signal light beams by one bit, and causes the two signal light beams to interfere to effect conversion into intensity-modulated light;

a balanced detection circuit which performs photoelectric conversion of signal light from two output ports of the Mach-Zehnder interferometer, and outputs a difference in converted electrical signals;

a low-frequency signal generation circuit which applies a first low-frequency signal at frequency f1 to the phase-adjustment terminal of the Mach-Zehnder interferometer;

an infinitesimal-modulated signal component detection circuit which detects a second low-frequency signal from a signal supplied by the balanced detection circuit;

a synchronous detection circuit which detects a shift amount and direction of shift between a center wavelength of the phase-modulated light output from the optical

transmitter and a pass band wavelength of the Mach-Zehnder interferometer, through synchronous detection of the second low-frequency signal output from the infinitesimal-modulated signal component detection circuit using the first low-frequency signal output from the low-frequency signal generation circuit;

a control circuit which outputs a control signal to adjust the phase difference between the two split signal light beams so as to correct the shift amount; and

a driver circuit which drives the phase adjustment terminal based on the control signal.

26. The optical receiver of an optical transmission system according to Claim 25,

wherein the infinitesimal-modulated signal component detection circuit comprises: an eye-opening monitoring circuit which outputs a signal obtained by monitoring an eye opening of a signal split from the signal output from the balanced detection circuit; and a band-pass filter which passes the second low-frequency signal contained in the signal output from the eye-opening monitoring circuit, and

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

27. The optical receiver of an optical transmission system according to Claim 25,

wherein the infinitesimal-modulated signal component detection circuit comprises: a data regeneration circuit which discriminates and regenerates an electrical signal output from the balanced detection circuit and which is provided with a code error detection function; an error count monitoring circuit which outputs a signal obtained by monitoring the number of errors output from the data regeneration circuit; and a band-pass filter which passes the second low-frequency signal contained in the signal output from the error count monitoring circuit,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

28. The optical receiver of an optical transmission system according to Claim 25, wherein the balanced detection circuit comprises an equalizing amplification circuit, the infinitesimal-modulated signal component detection circuit comprises: a current consumption monitoring circuit which outputs a signal obtained by monitoring the current consumption of the equalizing amplification circuit; and a band-pass filter which passes

the second low-frequency signal contained in the signal output by the current consumption monitoring circuit, and the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

29. The optical receiver of an optical transmission system according to Claim 25,

wherein the balanced detection circuit comprises: an optical splitting unit which splits into two each of the two output ports of the Mach-Zehnder interferometer; an optical coupling unit which causes interference between two light beams split by the optical splitting unit; and an optical detection unit which converts an optical signal output from the optical coupling unit into an electrical signal,

the infinitesimal-modulated signal component detection circuit comprises a band-pass filter which passes the second low-frequency signal contained in the electrical signal output from the optical detection unit,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

30. The optical receiver of an optical transmission system according to Claim 25,

wherein a free spectral range of the Mach-Zehnder interferometer is shifted somewhat from the clock rate of a main signal,

the infinitesimal-modulated signal component detection circuit comprises: a first amplifier which amplifies an optical current of one of photodetectors forming the balanced optical detection circuit; and a band-pass filter which extracts a component of the second low-frequency signal from an output of the first amplifier,

the synchronous detection circuit detects the shift amount and direction based on an output signal of the band-pass filter.

31. The optical receiver of an optical transmission system according to Claim 30,

wherein the infinitesimal-modulated signal component detection circuit comprises: a second amplifier which amplifies an optical current of the other photodetector forming the balanced detection circuit; and a subtracter which outputs a difference between the output of the first amplifier and an output of the second amplifier,

the band-pass filter extracts the component of the second low-frequency signal from an output of the subtracter.

32. The optical receiver of an optical transmission system according to Claim 25,

wherein the infinitesimal-modulated signal component detection circuit comprises: a clock extraction circuit which extracts a clock signal from a signal train output from the balanced detection circuit; and a low-frequency signal extraction circuit which extracts the second low-frequency signal superposed on the clock signal output from the clock extraction circuit,

the synchronous detection circuit detects the shift amount and direction based on the second low-frequency signal output from the low-frequency signal extraction circuit.

33. The optical transmission receiver of an optical transmission system according to Claim 25, wherein the infinitesimal-modulated signal component detection circuit comprises: a data regeneration circuit which discriminates and regenerates an electrical signal output from the balanced detection circuit; a correlation detection circuit which detects a correlation between an output signal of the

data regeneration circuit and a signal before discrimination; and a low-frequency signal extraction circuit which extracts the second low-frequency signal from an output of the correlation detection circuit.

34. The optical receiver of an optical transmission system according to Claim 25,

wherein the optical receiver comprises: an intensity modulation unit which performs intensity modulation of the phase-modulated light using a signal at frequency f2 sufficiently high to enable superpositioning of the low-frequency signal at frequency f1; and an intensity-modulated component detection unit which detects an intensity-modulated component at the frequency f2,

the infinitesimal-modulated signal component detection circuit extracts the second low-frequency signal at frequency f1 superposed onto the detected intensity-modulated component at the frequency f2.

35. The optical receiver of an optical transmission system according to Claim 34, wherein, as the intensity modulation unit, the optical receiver comprises: an oscillation circuit which generates a signal at the frequency f2; and an intensity modulator which performs

intensity modulation of signal light using the signal output from the oscillation circuit.

36. The optical receiver of an optical transmission system according to Claim 34, wherein, as the intensity modulation unit, the optical receiver comprises: an oscillation circuit which generates a signal at the frequency f2; and an optical amplifier connected to the oscillation circuit, and that the gain of the optical amplifier is modulated by the oscillation circuit at the frequency f2.

37. The optical receiver of an optical transmission system according to any one of Claims 34 to 36, wherein, as the intensity-modulated component detection unit, the optical receiver comprises: an optical splitting circuit which splits one of the two output ports of the Mach-Zehnder interferometer; a monitoring photodetector connected to the optical splitting circuit; and an extraction circuit which extracts the component at the frequency f2 from intensity-modulated light output from the monitoring photodetector.

38. The optical receiver of an optical transmission system according to any one of Claims 34 to 36, wherein, as

the intensity-modulated component detection unit, the optical receiver comprises: an input level adjustment unit which renders asymmetric input levels of the converted intensity-modulated light which is input to the balanced detection circuit; and an extraction circuit which extracts the component at the frequency f2 from an output signal of the balanced detection circuit.

39. The optical receiver of an optical transmission system according to any one of Claims 25 through 38,

wherein the infinitesimal-modulated signal component detection circuit comprises a data regeneration circuit which discriminates and regenerates an electrical signal output from the balanced detection circuit,

the optical receiver further comprises: a logic inversion circuit which inverts the logic of an output signal of the data regeneration circuit and outputs an inverted signal; a selection unit which selectively outputs either the output signal of the data regeneration circuit or an output of the logic inversion circuit according to a prescribed logic specification signal; and a polarity selection unit which inverts the polarity of a feedback error signal within the control circuit when the output of the logic inversion circuit has been selected,

an amount of correction of the shift between the center wavelength of the phase-modulated light output from the optical transmitter and the pass band wavelength of the Mach-Zehnder interferometer is reduced to 1/2 or less of a repetition frequency of the Mach-Zehnder interferometer.

40. The optical receiver of an optical transmission system according to any one of Claims 25 through 39,

wherein the optical receiver further comprises: a temperature detection circuit which detects the temperature of a substrate of the Mach-Zehnder interferometer; and a loop open/close switch which turns on and off feedback control to the Mach-Zehnder interferometer,

when the temperature of the substrate of the Mach-Zehnder interferometer is not within an appropriate range, the loop which performs the feedback control is opened, whereas when the temperature of the substrate of the Mach-Zehnder interferometer is within the appropriate range the loop is closed to perform the feedback control.

41. The optical receiver of an optical transmission system according to any one of Claims 25 through 39,

wherein the control circuit further comprises: a lock detection circuit which detects a locked state of a loop to perform feedback control to the Mach-Zehnder

interferometer; and a re-locking circuit which re-locks the loop when the locked state indicates that the loop is unlocked,

when the lock detection circuit is detecting that the loop is locked, normal feedback control is performed, and when the lock detection circuit is not detecting that the loop is locked, a driving signal applied to the phase adjustment terminal of the Mach-Zehnder interferometer is swept, and if the lock detection circuit once again detects that the loop is locked, switching to a state in which the normal feedback control is performed.

42. The optical receiver of an optical transmission system according to any one of Claims 25 to 39, wherein the Mach-Zehnder interferometer comprises two independent phase adjustment terminals, and an output of the infinitesimal-modulated signal oscillation circuit is applied to one of the two phase adjustment terminals, while a feedback error signal within the control circuit is applied to the other of the two phase adjustment terminals.

43. The optical receiver of an optical transmission system according to any one of Claims 25 to 39, wherein

the optical receiver comprises: an optical carrier frequency detection unit which detects, from received

signal light detected by the balanced detection circuit, a relative position between an optical carrier frequency and an optical frequency characteristic of the Mach-Zehnder interferometer; and an offset setting circuit which provides an offset to a feedback error signal in the control circuit,

a value of the offset of the offset setting circuit is adjusted such that the position of the optical carrier frequency matches a peak position or bottom position of the optical frequency characteristic of the Mach-Zehnder interferometer.